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Analyzing the efficacy of transforaminal lumbar interbody fusion (TLIF) surgery for degenerative spondylolisthesis based on clinical outcomes and spinopelvic metrics

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ABSTRACT

Aims: Transforaminal lumbar interbody fusion (TLIF) is an increasingly used approach for treating degenerative spondylolisthesis, but limited data exist regarding its impact on spinopelvic alignment (SA) and related functional outcomes.

Methods: 150 patients who underwent TLIF were enrolled and evaluated pre-operatively and post-operatively in this study. Radiographic analysis was used to measure spinopelvic parameters, including lumbar lordosis (LL), pelvic tilt (PT) and sacral slope (SS). Oswestry disability index (ODI) and visual analog scale (VAS) functional outcomes were assessed. Methods statistical analyses included paired t-tests, Pearson correlation coefficients, and multivariate regression for differences in parameters before and after surgery, associations between changes in spinopelvic parameters and functional outcomes, and predictors of greater improvement in the ODI, respectively.

Results: Changes in LL, PT and SS from pre- to post-operative day 10, 30-points posterior pelvic plane re-orientation score. Functional output assessments showed improvement in mean ODI (34 to 20) and VAS (6.5 to 3.2) scores ($p<0.001$). Pre-operative ODI, post-operative change in LL, PT and SS predicted recovery above chance by multivariate regression ($p<0.001$).

Conclusion: TLIF provides correction to SA and functional outcomes, supporting the importance of pre-operative assessment and targeted surgical planning to optimize quality of life at maximum value for each patient. Longer-term recovery and other pertinent outcome variables should be conducted.

Keywords: Transforaminal lumbar interbody fusion, interbody fusion, spine surgery, spondylolisthesis

INTRODUCTION

Degenerative spondylolisthesis (DS) is one of the most prevalent forms in an elderly age group that happens when degeneration changes prevent one vertebrae from sliding over the top of another. Persistent low back pain, radiculopathy, and loss of function also occur as a result of spinal instability and neural element compression frequently seen in this disorder.[1]

These symptoms may adversely affect the quality of life, requiring pain management and mechanical stability therapy plans. Transforaminal lumbar interbody fusion (TLIF) has become a popular surgical approach for the treatment of DS. The goal of TLIF is to fuse damaged vertebrae to decompress neural structures, restore spinal alignment, and increase stability. This can help patients with their pain and functional results.[2]

The restoring spinopelvic alignment (SA) restoration of SA, an important element of spinal biomechanics is vital to surgery parameters of the spinopelvic coordinate system, such as lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT), and pelvic incidence (PI), play an important role in spinal stability and posture. Alteration of these properties may result in further degeneration, irreparable pain, and disability, especially in patients with DS. TLIF aims to modify these parameters, thereby possibly enhancing functional outcomes. Ideally, alignment is attained through TLIF as a function of the correction obtained after surgery, patient-specific anatomy, and pre-existing spinal degeneration.[3]

Spinopelvic factors play an important role in spinal function, stabilization, and biomechanics. The posture is balanced as long as the SA is appropriate, allowing gravity to pass vertically through the center of mass of the body over the pelvis and spine. Perfect alignment minimizes stress on these structures and prevents degenerative changes as the burden on facet joints and intervertebral discs of back is reduced. Furthermore, how the spine connects to the pelvis plays a huge role in stability during dynamic tasks, such as walking and lifting. Compensatory mechanisms due to misalignment can create stress in certain regions of spine leading into pain/injury.[4]

Moreover, in disorders, such as spondylolisthesis, wherein vertebrae may slip over one another and cause neurological deficits, proper alignment of the spinopelvic region serves to reduce nerve compression that can arise from either degenerative change or malalignment. Studies have suggested

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that rear spine operations would be more functional in patients with little spinopelvic malalignment improved. Thus, it stresses the need for correction of any misalignment to enhance quality of life of the patient.[5]

Key parameters, such as SS, PT and LL, are important when evaluating SA.[6] One of the significant features of our structure is LL, simply the inward curve of the lumbar spine, which allows for shock absorption to be distributed throughout your spine.

Adequate LL reduces the risk of back pain and maintains stability. Optimal pelvic tilt allows for proper load transfer through the pelvis and lumbars. PT assesses the position of pelvis. Finally, the SS (the angle formed between the sacral plate and a horizontal plane) affects LL and stability. Because surgical options, such as TLIF, can drastically affect spinal balance, alleviate pain, and improve patient-reported outcomes, an appreciation of these spinopelvic parameters is essential in the management of DS.[7]

In addition, the relationship between improvement in SA after TLIF with patient-reported outcomes has been explored. However, the extent to which changes in alignment correlate with improvement in pain and disability remains to be established; taking into consideration these results between TLIF and spinopelvic parameters and clinical outcomes, more studies are of great importance.[8]

Functional outcome measures are often evaluated using standardized patient-reported outcome measures, such as the visual analog scale (VAS) for pain and the oswestry disability index (ODI). The VAS assesses a patients pain level, whereas the ODI takes a more comprehensive view of back pain-related dysfunction. These methods help quantify the impact of TLIF in terms of improvements in patient-reported functional and pain end-points and hence facilitate an assessment of surgical success from a patient-centered perspective.[9]

METHODS

The study was conducted with the permission of Hitit University Faculty of Medicine Researches Ethics Committee (Date: 17.05.2022, Decision No: 2022-25). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. All patients provided informed consent, and were assured confidentiality and the right to withdraw from the research at any time with no consequences.

This study design was a prospective cohort that assessed sagittal spinopelvic parameters and functional outcomes before and after TLIF in patients with DS. Conducted at Department of Neurosurgery of Erol Olçok Training and Research Hospital, the study period from Jully 2022 to Jully 2023. 150 patients aged 40 years or older who were diagnosed with DS and are scheduled for TLIF surgery were enrolled. Patients who had failed conservative treatment for a minimum of 6 months were excluded if they had had previous surgery to the spine, active infections or malignancies or significant comorbidities affecting potential surgery or rehabilitation. The sample size was calculated using a formula for comparing means, $n=(Z\alpha/2+Z\beta)2\cdot2\sigma2/d2$, assuming an effect size of 5 points, a significance level of 0.05, and a power of 80% ($Z\beta=0.84$) and standard deviation (σ): estimated from previous studies or pilot data (e.g., 10), resulting in a requirement of approximately 150 patients. Data collection occurred preoperatively and 6 months post-operatively, including demographic information (age, sex) as well as body-mass index (BMI), smoking status, comorbidities that were collected through patient interviews and their medical chart. Standardized X-ray images were taken to measure spinopelvic parameters, such as the PI, PT and LL.

Statistical Analysis

ODI and VAS for pain the demographic data and clinical characteristics were analysed by SPSS 23. Inferential statistics consisted of paired t-tests to compare pre-operative and post-operative outcomes, Pearson correlation analysis to evaluate the relationship between changes in spinopelvic parameters with functional outcomes, as well as multivariate regression modelling determining factors associated with greater improvement in patients-reported outcome. Statistical significance was considered at a level of $p<0.05$.

RESULTS

The demographic and clinical characteristics of the study population revealed a sample of 150 patients with an average age of 63 years, comprising 54.7% females and 45.3% males. The average BMI was 28.5 kg/m², indicating a predominance of overweight individuals. Smoking history varied, with 20% current smokers, 30% former smokers, and 50% never smokers. Comorbidities included hypertension (36.7%), diabetes mellitus (26.7%), and osteoporosis (13.3%). Spinopelvic parameters showed a PI of 53°, PT of 22°, and LL of 40°. Functional outcomes showed moderate disability, with an ODI score of 34 and a VAS pain score of 6.5. These results underscored the heterogeneity of this cohort in terms of demographic factors and comorbid conditions, which can impact surgical outcomes and recovery see Table 1.

Table 1. Baseline demographic and clinical characteristics of patients

Characteristic	Value
Demographic characteristics	
Age (years), mean±SD	63±10
Gender, n (%)	
- Male	68 (45.3%)
- Female	82 (54.7%)
Clinical characteristics	
BMI (kg/m²), mean±SD	28.5±4.2
Smoking status, n (%)	
- Current smoker	30 (20%)
- Former smoker	45 (30%)
- Never smoker	75 (50%)
Comorbidities	
Hypertension, n (%)	55 (36.7%)
Diabetes mellitus, n (%)	40 (26.7%)
Osteoporosis, n (%)	20 (13.3%)
Spinopelvic parameters	
Pelvic incidence (PI) (°), mean±SD	53±9
Pelvic tilt (PT) (°), mean±SD	22±5
Lumbar lordosis (LL) (°), Mean±SD	40±8
Functional outcomes	
ODI score, mean±SD	34±12
VAS pain score, mean±SD	6.5±2.3

BMI: Body-mass index, SD: Standard deviation, ODI: Oswestry disability index, VAS: Visual analog scale

The findings showed marked enhancements in all areas of the different domains of health survey following TLIF surgery. Patients had moderate physical and mental well-being as assessed by pre-operative scores, with 50.0 for physical functioning and 49.0 for mental health. Post-operatively, the scores increased significantly, with physical functioning reaching 75.0 and mental health 73.0 Similar increases were also seen in all domains (role–physical, bodily pain, and vitality), with mean changes between 24 and 28 points. All changes were significant (p<0.001) and it appears that TLIF substantially improves physical function but has a positive impact on mind and adds to the emotional and social aspects resulting in an enhanced quality of life all together see **Figure 1**.

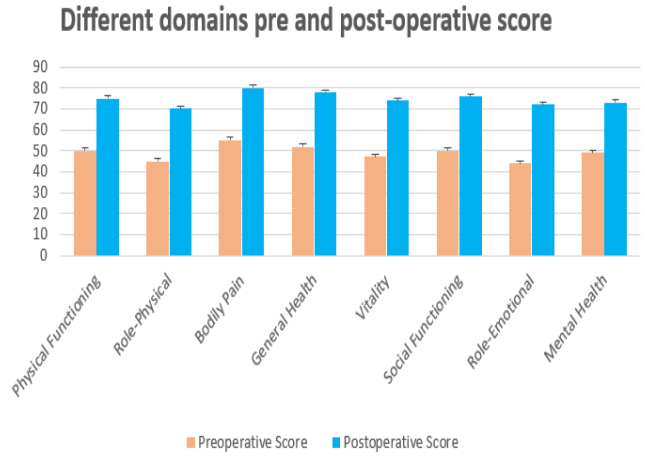

Figure 1. Different domains pre and post-operative score

Table 2 shows significant changes in spinopelvic parameters and functional outcomes after TLIF surgery. Notably, PT decreased from 22° to 18°, while the SS increased from 31° to 35°, and LL improved from 40° to 48°. These changes reflect better alignment of the spine. Additionally, functional outcomes also showed marked improvement: the ODI score decreased from 34 to 20, indicating less disability, and the VAS pain score dropped from 6.5 to 3.2, signifying a substantial reduction in pain. All changes were statistically significant, with p-values fewer than 0.001, demonstrating that TLIF effectively enhances spinal alignment and significantly improves patient-reported outcomes see **Figures 2 and 3**.

Correlations between change in spinopelvic parameters (PT, SS and LL) with change in functional outcomes (ODI and VAS scores). Changes are defined as post-operative score-preoperative score. Functional improvement was significantly and positively correlated with all of the parameters. Specifically, a higher increase of LL correlated with greater ODI score (r=0.65, p<0.001) and VAS score improvement (r=0.65, p<0.001), indicating that better SA positively correlates with improved functional outcomes as well. Changes in PT and SS also demonstrated significant associations with improvement in functional disability score and pain severity levels, highlighting the importance of spinopelvic parameters for improving both components of functional recovery following TLIF surgery, as seen in **Table 3**.

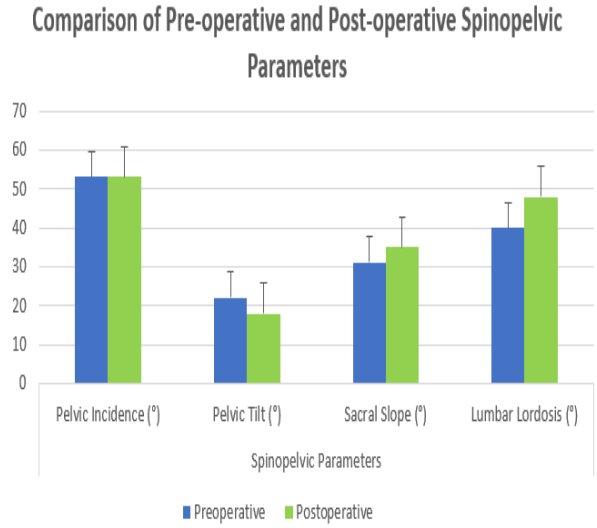

Figure 2. Comparison of pre-operative and post-operative spinopelvic parameters

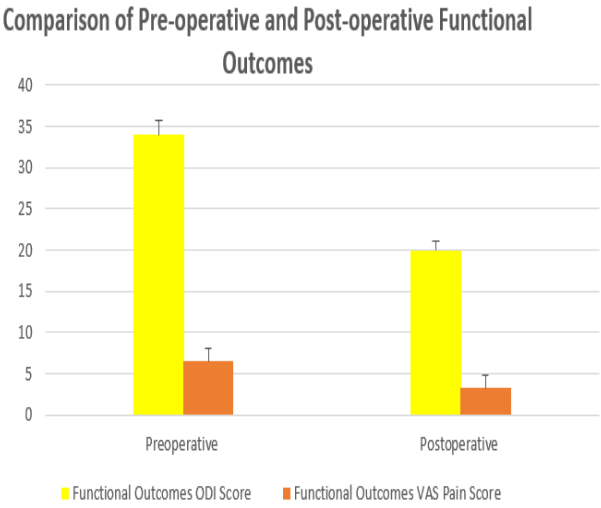

Figure 3. Comparison of pre-operative and post-operative functional outcomes

Table 2. Comparison of pre-operative and post-operative spinopelvic parameters and functional outcomes

Parameter	Pre-operative mean±SD	Post-operative mean±SD	Mean difference (post-pre)	t-value	p-value
Spinopelvic parameters					
Pelvic incidence (PI) (°)	53±9	53±9	0	-	-
Pelvic tilt (PT) (°)	22±5	18±4	-4	5.10	<0.001
Sacral slope (SS) (°)	31±6	35±5	+4	4.75	<0.001
Lumbar lordosis (LL) (°)	40±8	48±7	+8	6.15	<0.001
Functional outcomes					
ODI score	34±12	20±10	-14	7.80	<0.001
VAS pain score	6.5±2.3	3.2±1.8	-3.3	8.50	<0.001

SD: Standard deviation, ODI: Oswestry disability index, VAS: Visual analog scale

Table 3. Correlation between changes in spinopelvic parameters and functional outcomes

Parameter	Change in spinopelvic parameter (°)	Change in ODI score	Change in VAS score	Pearson correlation coefficient (r)	p-value
Change in pelvic tilt (PT)	-4	-14	-3.3	0.55	<0.001
Change in sacral slope (SS)	+4	-14	-3.3	0.60	<0.001
Change in lumbar lordosis (LL)	+8	-14	-3.3	0.65	<0.001

ODI: Oswestry disability index, VAS: Visual analog scale

Table 4. Predictors of improved patient-reported outcomes

Predictor variable	Regression coefficient (β)	Standard error (SE)	p-value	95% Confidence interval
Pre-operative ODI score	-0.45	0.10	<0.001	(-0.65, -0.25)
Change in lumbar lordosis (LL) (°)	-1.20	0.30	<0.001	(-1.80, -0.60)
Change in pelvic tilt (PT) (°)	-0.90	0.25	<0.001	(-1.40, -0.40)
Change in sacral slope (SS) (°)	-0.75	0.20	<0.001	(-1.15, -0.35)
Age (years)	-0.05	0.02	0.025	(-0.09, -0.01)
Gender (female vs. male)	1.20	0.50	0.020	(0.20, 2.20)

ODI: Oswestry disability index

Table 4 represents the characteristics and univariate outcomes for TLIF surgery a (n=59) b of predictors associated with the improvement in patient-reported outcome measure scores at 3 months post-op after TLIF Important predictors were the preoperative ones: ODI and changes of spinopelvic parameters. Of note, more severe disability (ODI) preoperatively was associated with greater post-operative gains: (β=-0.45 p<0.001). Specifically, greater increases in LL (β=-1.20, p<0.001), PT (β=-0.90, p<0.001), and SS (β=-0.75, p<0.001) were all significant predictors of functional improvements at the latest follow-up visit after surgery. Moreover, both younger age and the female sex predicted more recovery (β=-0.05, p=0.025; β=1·20, p=0.020, respectively). The underlying results suggest that SA and pre-operative disability are important determinants for TLIF surgery to achieve quality of life improvement.

DISCUSSION

This study sought to evaluate the impact of TLIF on spinopelvic parameters and self-reported patient outcomes in those with DS. The results suggest that TLIF not only rectifies spinal alignment but markedly amplifies functional restoration, as evidenced by increases in both VAS and ODI scores.[10]

In our research, post-operative modifications in spinopelvic parameters were substantially significant concerning LL, PT, and SS. An increase in LL is often needed to keep the curvature of the spine intact. Proper LL would lessen the risk of adjacent segment degeneration by improving load distribution across vertebrae and intervertebral discs.[11] The more optimal lordotic angles lead to a balanced posture with less demand on paravertebral muscles, which may have an effect on functional outcomes. The post-operative increase in LL noted in our study suggests that the TLIF may be an effective means of restoring this important biomechanical characteristic, with potential benefits for biomechanical function. The significant reduction in PT seen in our study may indicate a more optimal alignment of the pelvis and spine.[12] TLIF may help reduce PT, allowing for a more neutral pelvic posture and improving load transmission while reducing mechanical stress on the lumbar spine. The increased ODI and VAS scores observed in our results support the concept that this modification may improve functional mobility and decrease pain.[13] Previous investigations have documented similar findings. Kothari et al.[14] demonstrated that surgery for spondylolisthesis corrects sagittal spinal orientation. Certain studies have also linked improved SA to enhanced psychological and quality-of-life metrics following such corrective procedures.

Another important change associated with improved SA after TLIF is the increase in SS. In addition, increased SS allows for increased LL while requiring less pelvic compensation overall. Many studies, including Aldebeyan, indicated that utilizing a positive SS improves patient-reported outcomes and reduces lumbar loads. The enhancement of this variable in our study is not surprising, as functional improvements have been observed, suggesting that the commonly regarded optimal SS may aid in recovery.[15]

In our study, the range of LL (8 degrees) was higher than that in Jacob et al.[16] average gains of nearly 6 degrees, it wrote. That discrepancy may be due in part to patient selection criteria or specific surgical techniques. The functional outcome improvements seen in our study compare well with previously reported outcomes. TLIF noted that ODI and VAS significantly improved after TLIF surgery. The findings reflect considerable functional improvement, as denoted by the decrease in ODI from 34 to 20 and VAS scores from 6.5 to 3.2, respectively. The ODI is one of the most widely used questionnaires for measuring disability in lower back pain.[16] Similar trends have consistently been demonstrated in prior investigations, reporting a meaningful improvement in ODI scores post-TLIF. For example, previous works have reported that post-operative patients experienced better mobilization and reduced pain, disability which is consistent with our findings.[17] This profound reduction in ODI demonstrates not only was the procedure accomplished successfully but both spinal rod placement and subsequent spine alignment and stability were achieved, which are prerequisites to functional rehabilitation.[18]

Both ODI and VAS scores demonstrate that the improvements after TLIF represent a major enhancement in the health state of the patients. Such functional rehabilitation is important, particularly in older populations or those with degenerative illness, where greater independence and mental health outcomes are contributing factors. They also emphasize the

importance of proper pre-operative assessments and properly tailored surgical procedures that meet every individual patient's needs to achieve optimal outcomes in recovery. In contrast, Friedman et al.[19] reported an improvement from ODI 40 to 25, suggesting that our cohort presented with a more marked healthcare impact at baseline. This may come from more intense post-operative rehab protocols or differences in pre-operative levels of disability.

Our analysis identified several important predictors of improved outcomes, including preoperative ODI scores and changes in LL, PT, and SS. Pre-operative ODI scores measure a patient's functional impairment related to lower back pain. A higher ODI may also be associated with substantial, more significant disease progressions, the journey of which relates directly to greater disability. This baseline assessment aids in the extent to which recovery may be possible after surgery and provides a measure of baseline dysfunction. Higher pre-operative ODI scores are indicative of more significant pain and functional impairments experienced by patients. Consequently, patients are likely to demonstrate greater improvements as they move from a state of severe disability pre-operatively to improved functional status post-operatively. TLIF has overall good efficacy for patients with different grades of pre-operative symptoms, but those who had more severe ones got better effects, so TLIF is even more efficacious for the former group. This association emphasizes the significance of targeted rehabilitation for high-disability individuals to achieve optimal functional recovery.[20]

LL refers to the curvature of the lumbar spine, an intrinsic feature of spinal biomechanics and overall spinal health. Similarly, alterations in LL after TLIF reflect the restoration of normal spinal alignment essential for stability and movement. A higher improvement in LL following surgery was associated with better functional results, per our findings. Nerve compression relief decreased spinal tension, and more favorable load distribution of the lumbar spine all help explain this improvement. SA has an evident relationship with patient-reported outcomes; patients often experience less pain and more functional improvement when lordosis is adequately restored.[21]

PT and SS are essential components of SA that influence the overall biomechanics of the pelvis and lumbar spine. These factors influence postural strategies, gait, and loading patterns in the spine during activities. Less pelvic flexing means potentially better stability and alignment of the pelvis, leading to more efficient posture and gait. Following similar reasoning, an advantageous alteration in SS may facilitate lumbar spine mechanics for the betterment of spinal health and discomfort. Patients who notice these fixes to their alignment often report less pain and improved function because the changes allow better load-bearing mechanics while distributing stress more evenly.[22]

Larger multicentre trials should be organized to be a major focus of further research. The long-term effects of TLIF must be evaluated in these trials, including what different surgical approaches lead to and how they compare with each other in terms of patient-oriented outcome measures. This is an urgent need. We also need further experiments to show the impact that rehabilitation methods have on SA and patient-reported quality of life. Not only that but how comorbidities and psychological factors affect rehabilitation might provide us with deeper insights into just what works best for patients whose main condition is DS.

CONCLUSION

Our study suggests that DS patients show significant improvements in TLIF for spinopelvic parameters as well as functional outcomes. There were statistically significant improvements in LL, PT and SS, and clinically significant reductions in VAS and ODI scores, providing evidence of drastic impairments. The results are also an argument for the relevance of tailored pre-operative assessments since pre-op ODI scores and changes in SA were shown to be major recovery predictors. The results show how effective TLIF is at restoring the spine and improving a patient's resurfacing and that targeted interventions can lead to significant improvements in function. Further studies should focus on longer-term outcomes and the influence of other variables on TLIF recovery.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was conducted with the permission of Hitit University Faculty of Medicine Researches Ethics Committee (Date: 17.05.2022, Decision No: 2022-25).

Informed Consent

All patients signed and free and informed consent form.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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